

The first condition mentioned above can be checked by equation (7) while the second condition can be checked by equation (8). Two additional criteria must be checked at the mobile to ensure the mobile does not interfere with microwave station A.

The interference caused by microwave station A on the mobile is estimated via the quality of pilot channels seen at the mobile. Signals from different base stations are distinguished by pseudo-random noise (PN) code with different time offsets[4]. The mobile unit acquires the strongest pilot by searching (correlating) all 32768 time shifts of the PN code. Based on these measurements, there are $M+1$ unknowns, $P_{r1}, P_{r2}, \dots, P_{rM}$, and $I_{A/M}$, where P_{r_i} denotes the received power at the mobile due to the pilot channel of base station i and $I_{A/M}$ denotes the interference from microwave station A to the mobile. Since there are more than $M+1$ equations²⁸ with $M+1$ unknowns, $I_{A/M}$ can be determined uniquely. It can be shown that the solution is quite simple²⁹. Assuming $I_{A/M}$ is known based on these measurements at the mobile, the mobile then can determine if equation (6) will be satisfied³⁰, with the addition of its signal. If equation (6) is satisfied, then criterion number one at the beginning of this section is satisfied. Next, the mobile needs to check if the E_b/N_o of the information bearing channel is above the specified threshold or not. This can be done by applying equation (12) which relates the bit energy to noise density ratio of the pilot channel to that of the forward traffic channel.

Figure 2 gives a simple algorithm which explains how the above procedures can be implemented at base stations and mobiles. A microprocessor that performs all the above computations can be designed and implemented at the mobile unit³¹. Equation (6) requires knowledge of the transmitter power of microwave station A, its bandwidth, and the original interference power from PCS mobiles to the microwave station A (without the additional mobile). This information can be obtained from the base station via the paging channel. However, this introduces complexity in the mobile unit. An easier technique which allows the mobile unit to provide interference protection for microwave station A is through the use of a fixed threshold in the mobile unit. If a worst case design is used, no information needs to be transmitted from the base station to the mobile unit. Methodology of a worst case design is presented in the next section.

28. M equations can be obtained by varying the index i from one to M in equation (10). An additional equation is obtained by putting interference from microwave station A to the mobile, $I_{A/M}$, on the numerator of equation (10).

29. Numerical methods such as Gaussian Elimination are not needed. The exact algorithm to determine interference from microwave users to PCS mobiles depends on the specific parameters of pilot channel strength measurement which are proprietary to Qualcomm.

30. The original value of interference power from mobiles (without the additional mobile) to the microwave station A can be passed to the new mobile via the paging channel.

31. With the advance of microprocessor technology, the above computations can be done easily and economically.

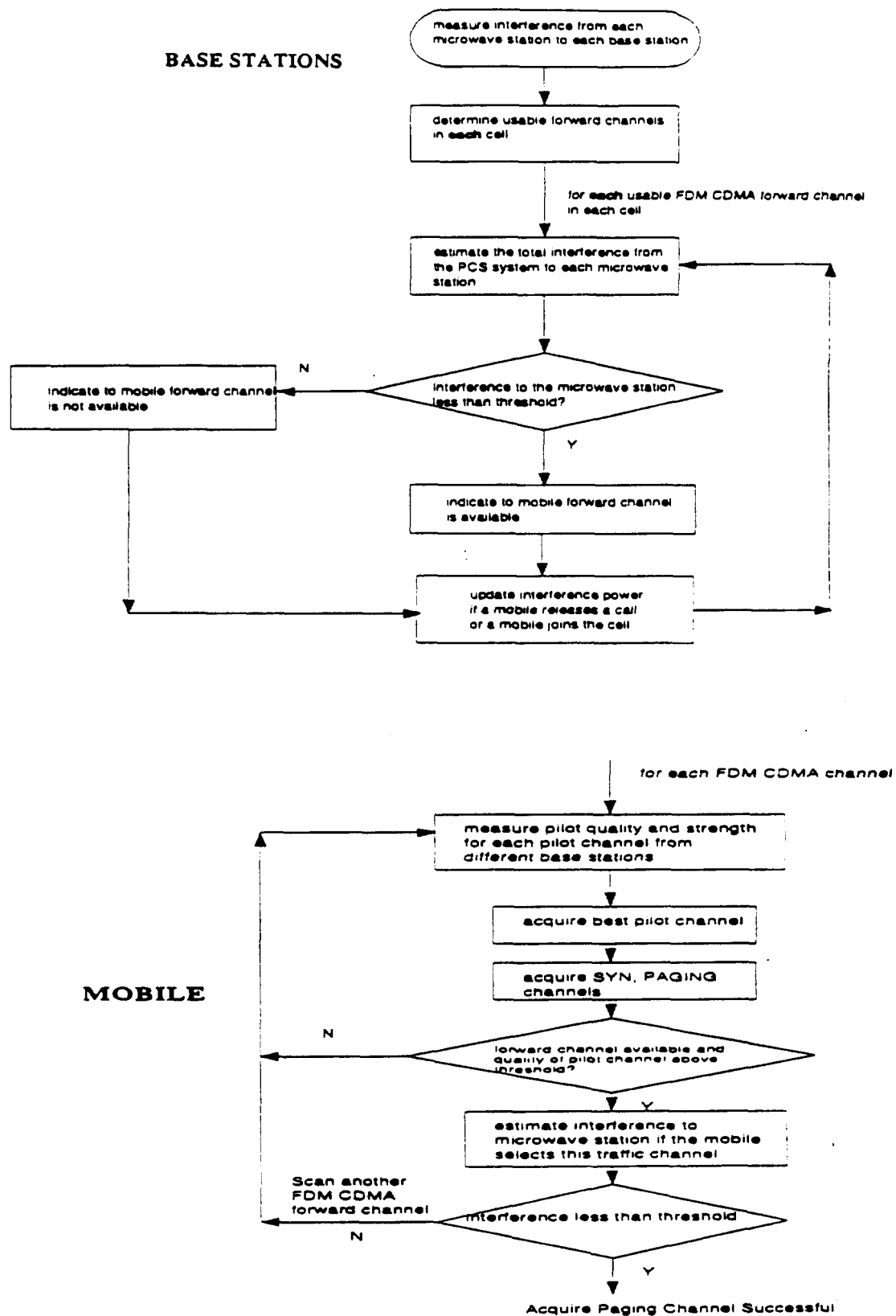


FIGURE 2. Interference Sensing in the ISCDMA system

3.2.1 Worst Case Interference Threshold Design

There are two types of interference experienced by a mobile unit: interference from neighboring base stations and interference from the microwave station A. If computations are not performed at the mobile that isolate powers received from the microwave station A, it becomes *impossible* to compute actual interference power due only to microwave station A, based on a single pilot quality (strongest pilot) measurement³² since the mobile will measure the summed power of microwave station A and all PCS base stations. However, it is possible to provide an upper bound of interference power from the microwave station A to the PCS by assuming microwave station A is the only source of interference, and setting a threshold for interference power from mobile units to microwave station A based on this worst case assumption. This solution trades simplicity in the mobile unit for a certain loss of capacity. Assume for the purpose of setting the necessary interference threshold that all interference received by PCS mobile units is caused by microwave station A. The interference from microwave station A to PCS mobiles should not exceed the worst case interference threshold, $Th_Interference$, in order to provide interference protection for microwave users. If the allowed interference power from all mobiles to the microwave station A is divided equally among each mobile, then the worst case interference threshold for a particular mobile is given by

$$I_{A/M_i} \leq \frac{ThPt(A)_{min}}{N_{max}Pt(M_i)_{max}\gamma_{max}} = Th_Interference \quad (EQ\ 14)$$

where γ_{max} is the maximum value of BW/1.23, $Pt(A)_{min}$ is the minimum transmitter power used by any microwave station in the market, $Pt(M_i)_{max}$ is the maximum transmitter power of the i^{th} mobile unit and N_{max} is the maximum number of mobiles in the PCS system. Therefore, the right hand side of equation (14) provides a worst case (minimum) interference threshold. Interference from microwave station A to the mobile, I_{A/M_i} , must not exceed $Th_interference$ if the microwave station A is guaranteed interference protection. All parameters in equation (14), except N_{max} , can be found by checking the specifications of microwave stations and mobile units. The main difficulty lies in the setting of N_{max} . If N_{max} is set very small, the system capacity will be limited. On the other hand, if N_{max} is set too large, the threshold may be too "tight" (i.e., threshold will be too small) so that some usable reverse channels are rejected from use. Further study is required to determine a reasonable value of N_{max} . Also, the degradation of capacity, using a worst case interference threshold, needs to be studied as well³³.

32. Hence, it is not possible to assign a bit-error rate (BER) threshold for the strongest pilot channel such that microwave station A is guaranteed protection.

33. It is clear that the approach presented in Section 3.2 is more complicated than that of Section 3.2.1. The capacity of the former approach will be higher than that of the latter one. Hence, there is a trade-off between complexity and capacity. If the values of $Pt(A)$ and γ do not vary by much, however, the system capacity using the latter approach will be close to the capacity using the former approach.

4.0 Multi-Microwave Links Sharing Same Frequencies

In this section, we expand the analysis of Section 3.0 and combine it with the analysis of Section 3.1. That is, the single microwave link is generalized to multi-microwave links sharing the same frequencies with multiple base stations/mobiles. However, only the concept rather than the mathematical detail is presented because the equations for this case are very similar to those in the previous two sections. Assume there are K microwave links sharing the same frequencies and denote the stations of each link as A_i, B_i for $i=1,2,\dots, K$. All the analysis performed above remains valid if the following steps are followed.

4.1 Estimation of Path Loss Between Each Microwave Link and Each Base Station

The total interference power from microwave users to the base station is a superposition of interference powers from each microwave user sharing the same frequency. Therefore, the measurement of interference power at the base station is a sum of interference powers from each microwave station. Equation (1) is modified as follows to include the effects of multiple microwave stations.

$$I_{MICRO/BS_j} = \sum_{i=1}^K \frac{P_t(B_i)}{PL_{B_i/BS_j}} \quad (\text{EQ 15})$$

where I_{MICRO/BS_j} is the interference power from all microwave users to the base station j , PL_{B_i/BS_j} is the propagation loss (absorbing antenna gains) from the microwave station B_i to the base station j . Note that I_{MICRO/BS_j} is the power quantity measured by the base station j . From equation (15), it is easy to show that the propagation loss from each microwave station B_i to the base station j is always larger than $P_t(B_i) / I_{MICRO/BS_j}$. Therefore, we have a *minimum* path loss between the base station and each microwave station B_i , and the *maximum* interference power from the base station to each microwave user B_i can be computed. That is, by applying the minimum path loss between each microwave link B_i and the base station to equation (3), the worst case interference from the base station to each microwave station B_i is known. If all of the worst case interference levels from the base station to each microwave station B_i is below the tolerable threshold Th_{B_i} , as defined earlier [7], [16], the base station can transmit at that frequency without interfering with any microwave station B_i . A similar equation can be derived for the propagation loss between each mobile and each microwave station, and the same approach as explained above can be used to ensure all microwave stations A_i are not interfered by the mobiles.

4.2 Interference Protection

Interference protection for microwave stations can be achieved by applying (6) and (7) for all the microwave stations. That is, A and B in equations (6) and (7) becomes A_i and B_i , and we need to determine if equations (6) and (7) are satisfied or not for K microwave links.

4.3 PCS Communication Quality

The criteria for good communication quality of the PCS system is the same as before. No matter whether there is one microwave link or there are multiple microwave links sharing the same frequencies, equations (8) and (11) must be satisfied in order to provide the minimum performance level. The only modification in equations (8) and (11) is that the sum of the interference powers from multiple microwave stations must appear in the denominator, rather than just the interference from a single microwave station.

5.0 Advantages of the ISCDMA Technology

5.1 High Capacity

The capacity advantage of the ISCDMA technology is based on the characteristics of spread spectrum as well as the properties of the described interference sensing techniques. The combination of spread spectrum modulation and interference sensing algorithms provides high capacity in the spectrum sharing environment. In fact, employing spread spectrum modulation in the ISCDMA technology is mainly due to capacity arguments. Spread spectrum has been used for anti-jamming applications since the second world war. Only recently has spread spectrum been proposed for code division multiple access (CDMA) to support high capacity wireless digital communications [11]. Various studies [5], [12] show that CDMA is capable of providing higher capacity than traditional frequency division multiple access (FDMA) and time division multiple access (TDMA) techniques. The CDMA technique can provide higher capacity because of the nature of human speech. It was shown that people speak at an average of 35% to 40% of the time during conversations [13]. For the rest of the time, people are listening. The percentage of time that people speak in a conversation is referred as the *voice activity cycle*³⁴. Based on a 35% voice activity cycle, the total co-channel interference within the PCS system is reduced by a factor of three. A smaller interference term appearing in the denominator of equation (8) translates to a higher system capacity with the same communication quality. In fact, CDMA is the only technology that takes advantage of the voice activity cycle in such a simple way.

The second way to increase capacity in a CDMA system can be achieved by sectorization of a cell. For example, with three antennas per cell cite, each antenna having a beamwidth of 120 degree, the total interference seen by each antenna is reduced by a

34. Voice activity cycle is ignored in the above equations to simplify analysis.

factor of three when compared to the non-sectorized case. Smaller interference seen by the antenna implies a high system capacity. Furthermore, CDMA can employ "graceful degradation"³⁵ under fully loaded conditions to accommodate extra users and thus the probability of blocked calls is reduced. Analytical studies [5], [12] showed that the capacity of a CDMA system can be as great as twenty times of the current cellular AMPS system. When CDMA is compared with the proposed US digital cellular standard (IS-54), CDMA can accommodate four to six times more users than the digital TDMA standard. The capacity improvement has been verified by Qualcomm through extensive field trials. Depending on the environments and other parameters, Qualcomm's CDMA system can provide at least ten times more users than the current analog cellular system. Therefore, the capacity advantage of CDMA technique has been demonstrated both theoretically and empirically.

The advantages of using CDMA over TDMA or FDMA in high interference environments are even more profound than in protected regular environments. The capacity of each CDMA channel in different cells can be varied according to the interference powers into and from the microwave stations. In areas with less interference, a high capacity CDMA channel can be achieved while a lower capacity channel can be provided in other areas so that the interference criteria for the microwave stations is not violated. In other multiple access techniques, the maximum load in a multiplexed channel is fixed and it is difficult to adjust the load of each multiplexed channel in different cells in order to satisfy the interference conditions. Therefore, in high interference areas, FDMA or TDMA must exclude some multiplexed channels from being used in the PCS. On the other hand, CDMA can automatically adjust its channel loading in different cells according to interference measurements. Thus, CDMA can provide higher system capacity in spectrum sharing environment than other multiple access techniques. The interference sensing techniques described here can optimize the available spectrum by measuring the interference from the microwave stations and then determine whether a particular frequency is available based on the criteria mentioned in Section 3.2.

It is possible that interference from microwave stations to the PCS mobile station is high in some part of a cell but is lower in the other parts of the cell. In the weak interference part of the cell, the frequency can be reused in the ISCDMA system. However, if a frequency co-ordination technique is used, that particular frequency cannot be used in the PCS system because the location of the mobile is generally unknown and hence frequency planners must perform a worst case design. Moreover, as explained subsequently, CDMA requires low transmitter power which translates into smaller interference power to the fixed microwave users. Since the total tolerable interference power for a microwave station is fixed, a lower PCS transmitter power enables more users transmitting at the same time without interfering with the microwave stations. Therefore, ISCDMA takes advantage of the high capacity property of CDMA and further optimizes the efficiency of the spectrum by interference sensing. It is clear that ISCDMA can provide higher capacity than other techniques such as TDMA, FDMA, exclusion zone

35. When the number of users exceeds the design value, it results in a degradation of transmission quality of all users rather than an access denial [11].

mapping, or a combination of those techniques. If all parameters of the microwave stations within the area are known (this is generally *a priori* knowledge), it is possible to determine how many users the ISCDMA system can support with a given amount of spectrum.

5.2 Quality

Since each CDMA portable handset is assigned a different code (Walsh function), transmission privacy is provided for each user. Moreover, since CDMA is a wide-band modulation technique, frequency diversity is naturally applied to the transmitted signal and thus fast Rayleigh fading is mitigated. This reduces the fade margin required in the system design and thus the required transmitter power is reduced. It also allows interference measurements to be made with less variance due to fading effects.

Soft handoff is employed when the mobile unit is close to the boundary of a cell. Both the new and old base stations transmit simultaneously the same information to the mobile unit until the mobile has moved into the region where the coverage can be well supported by the new base station. Thus, soft handoff improves the signal quality when the mobile is near the boundary of a cell. Because the old and the new base stations are transmitting at the same time when the mobile unit experiences signal degradation, a smaller power margin is required to overcome coverage problems when the mobile is close to the cell boundary. This leads to a smaller transmitter power which in turn leads to a higher system capacity as explained above. Other advantages of low transmitter power are discussed later in this section. Hard handoff can be used in high interference locations to avoid co-channel microwave interference. Thus, a combination of hard handoff, soft handoff and softer handoff³⁶ can provide good communication quality and high system capacity while the interference criteria for the microwave system is satisfied. Moreover, convolutional coding is used for forward error correction which can further enhance the transmission quality.

Qualcomm's DSCDMA system can exploit multipath components to provide path diversity by using multiple PN correlator receivers [4]. Path diversity can mitigate fades due to large physical obstructions, i.e. shadowing. At CTIA's "Presentation of the Results of the Next Generation Cellular Field Trials", Qualcomm's system demonstrated a better voice quality than the IS-54 system under interference conditions [4]. Again, the communication quality of CDMA has been verified both analytically and empirically. The communication quality of the fixed operational microwave users is guaranteed by the interference sensing technique. By combining interference sensing and CDMA modulation technique, ISCDMA can provide high quality personal communication services while the operation of microwave users is not interfered.

36. "Softer handoff" refers to the handoff between adjacent sectors of a cell.

5.3 Low Cost

At the moment, Qualcomm's DSCDMA is the most mature digital spread spectrum technology available. Little research work is needed to demonstrate the feasibility of Qualcomm's system because its quality, capacity and other operation characteristics such as power control and variable rate voice coding have been demonstrated in extensive field trials. In addition, the Qualcomm 1800 MHz PCS system has several built-in features to measure co-channel interference [4]. Interference sensing can be directly implemented into Qualcomm's DSCDMA system to take full advantages of these built-in features. Since ISCDMA requires little modification to Qualcomm's DSCDMA system, the manufacturing cost for the handset as well as the system operation cost should be low.

Unlike other frequency co-ordination techniques, ISCDMA does not require large scale measurements to determine zones where frequencies are usable. Furthermore, no frequency planning is needed for ISCDMA because frequency is re-used in neighboring cells as long as interference into microwave stations is tolerable. Frequency planning for other systems not employing spread spectrum and interference sensing can be a complicated procedure because frequencies are normally re-used in a 7-cell pattern and frequencies in some cells are not available due to excessive interference from the microwave stations to PCS or from PCS to microwave stations. A designed process to optimize the efficiency of the spectrum needs to consider both frequency re-use patterns and the available frequencies in different cells. Hence, the installation cost of ISCDMA is substantially decreased due to the fact that no large scale measurement and no complicated frequency planning is needed. The ISCDMA technology only requires the operation parameters of all microwave users in the area such as transmitter power, operating frequency, the type of communication system (e.g. FDM/FM, Digital Transmission), to be stored at each base station.

Moreover, as mentioned before, if ISCDMA is employed for PCS, the handset can be designed for use in all cities in U.S.A. Since a single handset is needed for all markets, mass production of the handset can further reduce the manufacturing cost of the handset. Since technologies required for the implementation of ISCDMA are available immediately, the use of ISCDMA for PCS can reduce the unnecessary PCS deployment delay which can threaten American leadership in wireless communications technology.

5.4 Low Transmitter Power

As mentioned above, CDMA system can utilize lower transmitter power than other systems because CDMA can mitigate fast fading and hence a smaller fade margin is required in the system design. Other reasons for small transmitter power is due to fact that path diversity provides protection against shadowing and soft handoff helps to solve the quality problem near handoff by transmitting the information from both the new and old base stations. Without soft handoff, larger transmitter powers are required to provide quality near the cell boundary. In fact, a small transmitter power can help to improve the system capacity in a spectrum sharing situation. Since the total allowable interference into a particular microwave station is fixed, a smaller handset transmitter power helps to

increase the maximum number of the co-channel PCS users without interfering with fixed microwave users. A smaller transmitter power also decreases the weight of the handset and makes the handset more convenient to carry. Moreover, a smaller transmitter power can help to increase the talk time of the handset before the battery needs to be recharged. Another important advantage of low transmitter power is the reduction of RF hazard. Excessive RF power can be harmful to human health [14]. It is important to minimize RF hazard while providing high quality universal personal communications services for all citizens at low cost.

5.5 Flexibility for Growth of PCS and Regulatory Simplicity

As the demand for PCS increases in the future, microwave users must be moved gradually to higher frequencies. The ISCDMA technology can automatically utilize the extra available spectrum without any hardware or software modification if a microwave user is removed from the 1850-1990 MHz band to other frequencies. This is not possible in other frequency co-ordination techniques because a precise frequency planning has been carried out. In the ISCDMA system, if some microwave towers are moved to other frequencies and new channels become available, the only adjustment needed is to modify the database of the microwave stations stored at the base stations. Furthermore, ISCDMA provides flexibility for additional microwave stations to be added into the 1850-1990 band if necessary. Again, this is not possible for other frequency co-ordination techniques. Therefore, ISCDMA provides flexibility for the growth of PCS and it does not limit new microwave users from adding to the spectrum. If an accepted interference computation scheme such as methods described in TSB-10E is used in the ISCDMA, the FCC can regulate the interference into microwave stations by simply checking whether standard interference computation methods are followed or not. In the ISCDMA system, it is easier for the FCC to regulate interference into microwave stations because a type accepted approach can be used. Interference regulation for frequency co-ordination techniques can be very complicated because it requires a complete map of available frequencies and large scale measurement work.

5.6 Universal Handset

As mentioned before, the handset of the ISCDMA system can be designed for use in any city throughout U.S.A. This not only reduces the complexity of design process, as mentioned above, it also reduces the cost of production. A universal handset is highly desirable because PCS services should be provided between any person no matter whether he or she is in the office, at home, or in another city. A universal handset satisfies one important goal of PCS services mentioned in NPRM by FCC, that is, universality of services.

5.7 Diversity of Services

Since Qualcomm's system can provide variable transmission rate, it can be tailored to serve different applications such as voice communication, wireless facsimile, and data transmission. This achieves another important goal of PCS defined by the NPRM [16],

that is, ISCDMA can be designed to serve a wide range of service. A long term goal of ISCDMA is to provide a broad range of advance communication services over a CDMA wireless networks.

6.0 Conclusion

We have established criteria for a frequency-division CDMA duplex channel to have tolerable interference to microwave links while maintaining good communication quality in the PCS system. By measuring interference power at the base station and assuming reciprocity of path loss for forward and reverse channels, the interference power to the microwave station can be estimated if its transmitted power is known. The pilot channel as well as the paging channel are used to ensure all the criteria explained in Section 3.2 are satisfied simultaneously. At the mobile, the communication quality of the forward link can be estimated by measuring the transmission quality of the pilot channel. If the transmission quality of the pilot channel is above a certain threshold, then the mobile needs to check whether the mobile will cause excessive interference to microwave users. Therefore, the transmit and receive frequencies of microwave links as well as their corresponding transmitter powers and operating bandwidths must be stored at each base station. This information then needs to be sent to the mobile via the paging channel. Alternatively, for simplicity in the mobile unit, a worst case interference threshold can be used to ensure interference protection for microwave users while avoiding transmission of microwave station parameters from the base station to the mobile unit. No interference mapping is required since all interference computations are done autonomously at base stations and mobiles. Also, we have discussed briefly how to expand the model to include the effects of multiple microwave stations sharing the same frequencies. Hence, we have demonstrated how ISCDMA can be used to solve the co-existence problem of the PCS system and fixed operational microwave users in a straightforward, easy-to-implement manner.

The main advantages of ISCDMA are its quality, high system capacity, simple interference regulation and universality of services. It is clear that ISCDMA is a cost-efficient method since minimum modification of current Qualcomm technology is required and no frequency availability map is needed. Moreover, this approach provides certainty of protection for fixed microwave users, and allows co-primary or even secondary use of the 1850-1990MHz band by a PCS system. We conclude that ISCDMA is an efficient and effective spectrum sharing technology for the emerging Personal Communication Systems. Further work is needed to implement the interference sensing algorithms derived herein, and to test their reliability in an actual PCS environment.

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**Comparison of Interference Sensing Code
Division Multiple Access (ISCDMA) and Frequency
Agile Sharing Technology (FAST)**

January 27, 1993

Executive Summary

A wide variety of technologies is proposed for realizing cordial co-existence of the fixed microwave users and the Personal Communication Services ("PCS") in 1850-1990 MHz band. In this report, Corporate Technology Partner's ("CTP") Interference Sensing Code Division Multiple Access ("ISCDMA") technology and American Personal Communication's ("APC") Frequency Agile Sharing Technology ("FAST"), are evaluated. The objective comparison is done from the viewpoints of a PCS operator as well as a fixed microwave user.

The ISCDMA is based on an algorithm which uses real-time field measurements and certain predetermined thresholds to distinguish the usable frequencies which will not cause harmful interference to the fixed microwave users and at the same time, provide good quality PCS service. The FAST technology, on the other hand, utilizes statistical predictions validated by field measurements to determine the exclusion zones.

Except for the strategy used to determine unusable channels, the ISCDMA and the FAST approaches appear similar in many ways. Both the approaches use frequency agility, dynamic channel allocation and set up calls on best channels to give added interference protection.

The real-time interference sensing as proposed in ISCDMA appears to provide higher capacity, lower cost, quick adaptability, more flexibility and greater reliability to a PCS operator. It is also superior in certainty of protection to the microwave users and in regulatory simplicity.

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1. Introduction

The purpose of this report is to perform an objective evaluation of workability of ISCDMA and FAST technologies. The two technologies are compared from the standpoints of a PCS operator as well as a fixed microwave user.

What are the relative costs of the two approaches in the initial implementation? How do the costs vary as a PCS system evolves through cell additions and sectorization to meet coverage and capacity demands? Which approach provides an operator with a greater capacity at a lower cost for serving a given body of subscribers? Which approach is more innovative? Which technology provides certainty of interference protection to the microwave users? Which methodology lends itself to simple and less cumbersome regulatory procedures? This report attempts to find answers to these and similar questions.

For the purpose of this study various documents were reviewed. Some of the main documents which were referred to during the course of this study are [1], [2], [3] and [4]. In addition, other major filings by APC, CTP and other pioneer's preference applicants were reviewed and independent research was conducted.

2. Overview of Interference Sensing Code Division Multiple Access (ISCDMA)

ISCDMA is a novel approach which combines an interference sensing method based on Code Division Multiple Access ("CDMA") pilot and paging channels and spread spectrum techniques to solve the co-existence problem of PCS and the existing fixed microwave users. The interference sensing mechanism provides an active protection for the fixed microwave users unlike APC's FAST technology which depends passively on *apriori* careful engineering of exclusion zones and yet does not guarantee interference protection for the fixed microwave users. A dynamic channel allocation process maximizes the system capacity by performing real-time interference measurements at mobiles and PCS bases stations.

Based on the analysis of the technology, the main advantages of ISCDMA appear to be its low cost, high system capacity, reliability, quality and unparalleled flexibility in interference regulation and universality of services. ISCDMA would be a cost-effective method which provides certainty of protection to the fixed microwave users. This elegant approach for interference control does not require interference mapping since all interference calculations are done autonomously at base stations and subscriber units based on a limited number of parameters which can either be factory installed or introduced upon installation of base stations.

One of the most important features of ISCDMA is that its interference calculations are based on real-time field measurements rather than empirical statistical models. This approach is superior in that the statistical models end up predicting the system behavior under "average" conditions. Implicit in their nature, the statistical models do not provide for worst case scenarios which are of prime concern in any interference analysis. In contrast, the real-time measurements performed under the ISCDMA scheme determine the system behavior under "actual" conditions and hence do not suffer from this limitation.

2.1. Interference Sensing Mechanism

The details of the ISCDMA interference sensing approach can be found in [1]. A brief summary is presented here. The interference sensing mechanism of the ISCDMA technology uses a built-in algorithm to estimate the interference levels to the fixed microwave users, based on the measurements performed at PCS base stations and mobiles. The estimated interference levels are then compared with certain predetermined thresholds to check the availability of the channel frequencies for PCS use. The most important aspect of the ISCDMA interference sensing scheme is that the measurements are performed in real-time, under actual, not theoretical conditions.

2.1.1. Interference Sensing at the Base Station

Each base station maintains a database containing certain operating parameters for the PCS system and neighboring microwave users (microwave users with ranges established under EIA/TIA bulletin TSB-10E). These include transmitter power, frequency and operating bandwidth for the microwave users. The database also includes the PCS base station powers and interference levels seen at PCS base station locations due to the fixed microwave transmission. Interference measurements from microwave stations to each base stations can be made prior to the operation of the PCS system and updated on a regular basis. Once such a database is established then all the channels are scanned and their usability is determined based on the following approach.

The interference measurements at PCS base stations are used to determine interference from PCS base stations to the fixed microwave links. These calculations are based on the assumptions that the PCS channels are reciprocal and the ratio of forward channel frequency to the reverse channel frequency is close to unity. Based on interference to the fixed microwave users due to the forward link frequency of a PCS channel, the maximum allowable PCS transmitter power at a base station is determined. If the maximum allowable power is less than the minimum power required to set-up a traffic channel, then the channel is deemed to be unusable.

In operation, when a call set-up is attempted between the base station and the subscriber unit, all available traffic channels are scanned. Each base station follows a two step procedure to determine if a forward traffic channel (which was predetermined to be

usable) is still usable or not, with each additional user in the system. The following two criteria must be satisfied simultaneously.

☐ The total interference by the forward link of the PCS system onto the microwave stations, with the additional interference caused by an additional user, is still within the required threshold, and,

☐ The transmission quality of the reverse link (as given by the bit energy to noise density ratio) is above the specified performance level, with the additional user.

2.1.2. Interference Sensing by the Mobile Unit

The interference caused by mobile units to the fixed microwave users is estimated via quality of PCS base station pilot channels seen at the mobile. Signals from different PCS base stations are distinguished by pseudo-random sequence (PN) code with different time offsets. Based on these pilot carrier measurements, interference from the fixed microwave links to a mobile can be determined uniquely. Please refer to [1] for the relevant equations. Interference to the fixed microwave by a mobile can now be calculated by using the reciprocity principle. If the interference is below the permitted threshold then the mobile goes on to checking quality of the forward link based on the bit energy to noise density ratio. Only when both these conditions are satisfied, a channel is acquired to set-up a call.

A microprocessor that performs the computations required for the above algorithm can be designed and implemented at the mobile unit. Alternately, an approach which involves fewer calculations can be implemented which provides a lower bound on the interference from the mobile to the fixed microwave users. This worst case design approach trades simplicity in the mobile unit for a certain loss of capacity.

Further details regarding ISCDMA can be found in [1]. Even though [1] primarily discusses the interference sensing algorithm as applied to CDMA scheme, it can be easily adapted for other modulation technologies. The ISCDMA technology appears to be eminently workable and would offer distinct advantages, such as, higher capacity, lower cost, certainty of protection to the fixed microwave users and regulatory simplicity compared to the exclusion zone approaches.

3: Overview of Frequency Agile Sharing Technology (FAST)

The Channel Utilization Controller (CUC) is a central component in APC's FAST approach. It is comprised of an operating system, coverage and interference analysis programs, measured data analysis programs, supporting databases and data communication links to each PCS base station.

The CUC determines an Available Channel List (ACL) or a frequency plan for each PCS base station based on theoretical interference analysis. The CUC then instructs each base station to measure the signal strength in each fixed microwave channel. The measured data is transmitted back to the CUC where it is compared with the theoretical predictions.

The measurements are also done for subscriber unit receive frequencies using a Test Mobile Unit (TMU). The CUC utilizes this measured data to verify potential interference at the fixed microwave receiver from subscriber units in the service area of a PCS base station.

From past experience, it is known that the process of integrating the measured data with the theoretical prediction is extremely complex and fuzzy. Certain subjective criteria based on a design engineer's experience have to be applied prudently to use the measured data for system design. Due to the complexities and randomness of a radio channel, a reliable automation of an exclusion zone mapping cycle, which includes signal prediction, measurements and data integration, appears almost impossible. Hence a quick and widespread implementation of an exclusion zone based scheme such as FAST, would be very unlikely.

PCS base stations measure signal strengths on every voice channel in the ACL and rank them by ascending signal strength. When the base station receives the subscriber unit's measured data, it ranks the subscriber unit's channels according to the same criteria. For each channel, the base station adds the subscriber unit rank to the base station rank and selects the channel with the lowest rank.

It is to be noted that except for the strategy used to determine the unusable channels, the FAST approach and ISCDMA approach are in many ways similar. Both approaches use

frequency agility, dynamic channel allocation and set up calls on "best" channels to give added interference protection. The major difference between the two approaches is that FAST uses cumbersome and expensive propagation analysis aided by measurements to determine unusable channels whereas ISCDMA is based on an algorithm which uses the data collected by real-time interference measurements. It is this difference that leads to various advantages within ISCDMA that are discussed in the next few pages.

4. Comparison of ISCDMA with FAST

4.1. Higher Capacity

The capacity advantages of ISCDMA scheme over the exclusion zone approaches are based on the inherent adaptive characteristics of the real-time interference sensing scheme as well as its ability to enhance the performance of the underlying CDMA scheme.

4.1.1. Utilizing Channels which May Be Unusable in Some Parts of a Cell Coverage Area but Usable Elsewhere

ISCDMA technology dynamically determines if a mobile at any given geographical location would cause harmful interference to the fixed microwave users or not. Alternately, using the similar terminology as the exclusion zone proponents, it can be said that, in ISCDMA the "tiny and precise exclusion zones" are determined dynamically under the actual geographical, weather and channel loading conditions. No statistical models are involved in this process. Hence the determination of areas where a mobile can use a particular channel is more precise and realistic. It allows the mobiles to operate in all that portion of the cell coverage area which is free of interference to fixed microwave. At the same time, the mobile operations are blocked in the area which may have potential interference to the fixed microwave users. The exclusion zones which are prefabricated with the help of statistical signal propagation model in FAST and other similar approaches, lack the resolution and precision of ISCDMA approach. Specifically, if an exclusion zone overlaps with any part of a cell coverage area, then the corresponding channels become unusable over the entire service area of the cell. This is because under exclusion zone approaches, the system has no way of measuring real-time local interference in the specific area where a mobile is operating. Consequently, under FAST, a channel which interferes in any part of a cell must be excluded from being used in the entire coverage area of the cell.

4.1.2. Use of Channels Under Lower Loading Conditions¹ That May be Unusable Under Higher Loading Conditions

As mentioned earlier, in ISCDMA, determination of so called "tiny and precise exclusion zones" is done under the actual channel loading conditions. A channel frequency which may cause interference to microwave users under higher loading conditions (i.e. high summed power), may not do so under lighter loading conditions (i.e. lower summed power). ISCDMA takes advantage of variable channel loading conditions in an automatic fashion and lets the subscriber use a channel if it does not interfere with the microwave users under the current loading conditions.

The predetermined exclusion zones in FAST technology do not account for variable channel loading conditions. The available channel list has to be determined based on the worst case scenario which assumes maximum channel loading. Doing otherwise would cause harmful interference to the fixed microwave when the channel is operating at its maximum loading condition (highest summed power). Hence, under FAST, there is no choice but to reject the channels which are actually usable under low demand conditions (low summed power). This is unrealistic, inefficient and results in reduced capacity.

4.1.3. Smaller Error Margins in ISCDMA Provide Higher Capacity

ISCDMA is a deterministic interference sensing scheme and does not rely not statistical signal prediction models unlike the FAST technology. Hence error margins required are much smaller compared to those required in exclusion zone determination in FAST. Smaller error margins result in larger area over which a mobile can operate without interfering with the fixed microwave users. This, in turn, leads to higher system capacity for ISCDMA compared to FAST or other exclusion zone technologies.

¹ In CDMA modulation scheme, loading condition refers to the number of subscribers on a channel at a given time. Addition of a subscriber, increases the transmission and receive power for that channel. A low loading condition refers to a low number of subscribers on a particular channel and hence it means a low summed power.

4.2. Lower Cost

4.2.1. Cost of Measurements

In the FAST approach, the operator needs to validate the signal predictions by controlled and extensive field measurements. The measurement database must be current and should keep up with any system changes in the fixed microwave links or the PCS system.

From the experience of cellular system design, it is known that performing reliable measurements and integrating them with the theoretical predictions constitutes a major and an expensive part of a design cycle. An addition of a cell site to the system or a change of operating parameters (either PCS or fixed microwave) would call for a field measurement and a data integration cycle pertaining to the entire PCS system or at least a major portion of the system. This may involve approximately 5 to 7 man days of effort depending on the size and maturity of the system. The effort involved in a field measurement and data integration cycle may increase as a system grows. A typical system may require, on an average, one field measurement and data integration cycle per month. Let the cost per one man day be \$800.00. Based on these assumptions, it will cost an operator \$67200.00 ($12 \times 7 \times 800$) per year just to keep the measurement database up to date. This cost does not include cost of the equipment rental and logistical arrangements. Moreover, it does not reflect the cost involved with delays and system downtime which are extremely likely with the field measurements. This cost analysis is just for one system. One can imagine the cost of field measurements if they would have to be done for the whole country or for the whole world!

From a practical system operator standpoint, FAST is too complicated and expensive for a widescale implementation in the U.S. and abroad.

ISCDMA, on the other hand, eliminates the field measurement and data integration part of the design cycle completely. Measurements are done on real-time basis and no *a priori* controlled measurements are required. This results in savings in revenue and reduced delays in the design cycle. ISCDMA is a practical approach to PCS frequency sharing which a system operator can handle.